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REPORT NO: 1949B-471 DATE 15 November 1954

TITLE: PULSEJET NOISE ANALYSIS

AUTHOR: Paul S. Veneklasen R. W. McJones

AMERICAN HELICOPTER

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AUTHOR: Paul S. Veneklasen R. W. McJones

MODEL NO. CONTRACT NO.

EXPENDITURE ORDER NO.

REVISIONS:

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APPROVED BY: N. M. Stefano, Chief Engineer

AMERICAN HELICOPTER

DIVISION OF FAIRCHILD ENGINE AND AIRPLANE CORPORATION

MANHATTAN BEACH, CALIF., - COSTA MESA, CALIF., - MESA, ARIZONA

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1.0 SUMMARY

Octave Band analyses of the noise spectra of pulsejet engines have been made as follows:

a. Engine sizes from 5" to 12.5" in diameter have been studied to determine the influence of engine size and rate of fuel flow upon the noise spectrum, operating frequency and thrust.

b. Noise Control configurations have been tested, including twin engines in parallel configuration with an acoustically treated cowl around the tailpipes, with an integral acoustic filter, and two types of serrated tailpipe.

Correlation of all available data indicates that noise level increases with thrust output for a given pulsejet, but that maximum thrust noise level is not a strong function of engine size.

2.0 INTRODUCTION

This report describes work accomplished under item 1.5 of Exhibit A, Change Order No. 6 of Contract AF33 (600)-5860.

The general objectives of this report are (a) to present the single and multiple engine pulsejet noise data obtained to date, and (b) to correlate this data on bases which will permit prediction of the noise performance of final power packages suitable for helicopter propulsion.

The application of this data to the preliminary design of the MX-1660 helicopter is described in Reference 4.

The present report is based largely on material previously published informally as a reference report, Reference 5.

3.0 DISCUSSION

3.1 INSTRUMENTATION

All the noise studies reported herein were made with Octave Band analyzing equipment consisting of the Western Electro-Acoustic Laboratory 1000B Sound Analyzer which uses the Western Electric 640AA Condenser Microphone. In all cases the noise history of an engine run was recorded on an Ampex 350 Magnetic Tape Recorder. The recordings were made on continuous tape reels. For analysis purposes, the tape may be retained in reel form or tape loops may be cut out and played continuously. In this manner it is possible to choose an appropriate short steady period of noise out of a run which may be either too short or variable for manual analysis. It is clear that the tape recorder is used only as a storage device. Its calibration and equalization can be adjusted very accurately and with this quality machine, can be counted on for stability over long periods of time. In using tape loops for analysis purposes, considerable caution must be exercised to insure that the tape loop is played back under identical tension conditions as when recording, so as to assure faithful reproduction of frequency. Proper facilities have been added to this equipment for this purpose. The fundamental operating frequency was measured for each engine condition.

All these noise analyses were made with the engines mounted on a static test stand within the partial enclosure which is used for noise control and was described in Reference 1. Photo 1 shows the 6.75" engine mounted on a test stand and is representative of the mounting of all engines used in these tests.

3.2 THE INFLUENCE OF ENGINE SIZE AND FUEL FLOW RATE ON NOISE SPECTRUM

Heretofore when it has been necessary to make calculations of expected noise from pulsejet engines, it has been necessary to extrapolate data from very limited experience with various sizes of engines. It has been assumed that noise output would be proportional to rate of fuel flow, that is, to power input. The following study shows that this assumption is far from true and demonstrates that other factors are of much greater importance in noise production by pulsejets. All measurements of noise spectra here reported were made at a distance of three feet from the center line of the engines on a perpendicular midway along their length, except for the 12.5" engine.

3.2.1 The 6.75" Standard Single Shell Engine

Most of this contractor's earlier studies in connection with the noise control program have used a single shell 6.75" engine, which has a tube length of 34 inches. It is only in deference to this previous work that this engine is called "standard". The noise output spectrum of this engine is shown in Figure (1) for several different fuel flow conditions. It will be noted that for the lowest rate of fuel flow the noise

spectrum is considerably reduced, whereas for higher values of fuel flow over a considerable range there is very little change in spectrum level.

3.2.2 The 6.75" Single Shell Engine with Long Tail Pipe

This engine is identical with the standard engine except for the tailpipe which is 4.5 inches in diameter and increases the over-all length to 44 inches. Figure (2) shows noise spectra for three different fuel flow rates. Values of thrust and operating frequency for various fuel flows are given with each figure.

3.2.3 The 7.5" Single Shell Engine

Figure (3) presents the noise spectra for this engine with appropriate rates of fuel flow. Again, the trend from a low value of noise production at low fuel flow rate to considerably higher values over a large range of higher fuel flow rates is most evident with this engine.

3.2.4 The 7.5" Conical Engine

This engine is like the previous one except for an additional conical shell which is shown in Photo 2. Figure 4 shows the noise spectra for this engine.

3.2.5 The 12.5" Single Shell Engine

Figure 5 shows noise spectra for four different fuel flows. This data shows the largest variation in high frequency noise spectrum, as a function of fuel flow, which has yet been found for a pulsejet engine. Note in contrast how small the variation is in the lower bands. It is also interesting to note the extreme variation in operating frequency which accompanies changes in fuel flow in this engine. This is one reason for the peculiar behavior of the noise spectra in the first two low frequency bands, because the fundamental frequency actually moves from one band into another. It would be more illuminating, although it does not at the moment seem worthwhile, to analyze these noise spectra in more detail so as to determine the levels of the prominent harmonic components which constitute the low frequency portion of a pulsejet noise spectrum. It should be pointed out that this engine was measured at a distance of six feet. In view of the difficulties of starting this engine and the expectation of considerably higher levels than were actually produced, it was not considered safe to leave the microphone in its usual fixed position; therefore the microphone was kept at a safe distance until the engine was operating stably, whereupon it was moved to the 6' position. Data from Figure 13 indicates that the spectrum may be approximately 2 to 3 db higher at the 3' position.

3.2.6 Comparison of Noise vs. Size

Noise spectra for each of the above engines for a typical medium fuel flow rate are combined in Figure 3.6. In this case the spectrum from the 12.5" engine is increased by 3 db for proper comparison; also the spectrum for a 9.4" engine is included, data being drawn from Reference 2. This data clearly indicates that there is no substance to the thesis that noise output is proportional to power input. This finding suggests that one should search elsewhere for the controlling factor in noise production.

Additional correlations of noise data from various pulse-jets will be presented in section 3.4 of the present report.

3.3 NOISE CONTROL CONFIGURATIONS

3.3.1 The 6.75" Engine with Acoustic Filter

One of the attempts in the study of noise control possibilities is represented in Photos 3 and 4, which show a simple acoustic filter built on the tailpipe of a 6.75" engine. This filter consists simply of an extra cylindrical shell around the tailpipe. The cavity so formed is connected with the tailpipe through perforations. The performance of this device is indicated in Figure 7, where its spectrum is compared with more typical 6.75" engines.

The greatly reduced thrust produced by this engine is indicative of lower average exhaust velocity since the effect of an acoustical filter is to convert a pulsating flow of gas into a steady flow. Unfortunately, this method of noise reduction is hardly tolerable, which emphasizes the difficulty of finding methods of noise control which will not destroy the thrust-producing mechanism of the pulsejet engine. It appears that a proper method must retain the pulsating output flow from the tailpipe and surround this outflow, for noise reduction, at a sufficient distance to avoid rearward reaction forces on the enclosing shroud.

In this same figure the comparison between two different tailpipe lengths is also most apparent. It is interesting to note in this comparison that the engine with the greater thrust produces the lower noise level. One possible explanation which will bear further study is as follows: the longer engine which encloses a larger mass of gases in the tailpipe probably produces its thrust by accelerating a larger mass of gas to a lower value of exhaust velocity.

3.3.2 Twin 6.75" Engines in Parallel Configuration

The following data continues tests of this configuration, to which considerable study has already been devoted. Photo 5 shows this configuration mounted on a test stand. The present tests were intended to study the effectiveness of a shroud having an acoustically absorbent lining, which is shown in Photo 6. Photos 7 and 8 show the enshrouded engine con-

figuration mounted on the test stand. The lining of the shroud consists of Refrasil wool (High temperature Fiberglas) which is held in place by a layer of Refrasil cloth and a perforated Inconel-X screen. It was not expected that this particular sample would be the last word in durability, not to mention performance. However, the Refrasil liner did stay in place long enough to permit the recording of noise samples. The results are shown in Figure 8, which shows the spectrum for the twin engines without shroud, for comparison with the spectrum produced by the engines in the treated shroud. The present tests confirm earlier experience with an untreated shroud, namely that the benefit furnished by the pairing of engines in the reduction of low frequency noise is to a large extent forfeited by the use of a shroud. However, the present tests also indicate a useful reduction in high frequency spectrum, which has not been hitherto achieved. It is not at present known why the use of a shroud restores the low frequency noise. Perhaps the length of the shroud has been unfortunately chosen so that the resonant frequencies characterized by this length are excited by the engine. Since temperature conditions within this shroud are hardly predictable, it is difficult to choose an appropriate length except on an empirical basis. However, if future work succeeds in achieving a combination of the low frequency noise reduction resulting from pairing, together with the high frequency reduction produced by a small treated shroud, useful progress in noise control will have been achieved.

3.3.3 Twin 6.75" Opposed Configuration

Photos 9 and 10 show the mounting on the test stand of the twin opposed configuration which has been tested previously. The present tests were intended to measure the performance of this configuration, using an acoustical liner for the common shroud, which diverts gases from the tailpipes. Photo 11 shows the result, which was simply to strew the lining material over the neighborhood. The material did not stay in place long enough to measure its effectiveness. It had been planned to test this material with small metal deflectors to protect the material from direct impingement, but these were not installed with the intention of determining the durability of the material. As a result the only noise records which are of value are shown in Figure 9, which is for the engine with common cowl but without liner.

3.3.4 The 6.75" Engine with Long Tailpipe and Tabs Extending from Tailpipe

Rectangular extensions were welded to the tailpipe, as shown in Photo 12. This experiment was an attempt to test the method proposed by the British, of serrating the tailpipe of a Jet engine. The theoretical background for such a proposal is not human. Figure 10 shows that the results were negative.

3.3.5 The 6.75" Engine with Long Slotted Tailpipe

This experiment was a slightly different attempt to test the British theory. Hacksaw slots were cut into the trailing edge of the tail-pipe for about the length of the flared section, as shown in Photo 13. Figure 11 again indicates insignificant results.

3.4 APPLICATION OF NOISE DATA TO HELICOPTER DESIGN

3.4.1 The Problem

The problem is to extrapolate from available data on the noise spectra from various sizes of pulsejet engines so as to estimate the spectra which are to be expected for various possible configurations of pulsejet engines which may be capable of driving a helicopter rotor. The purpose of this investigation is to clarify the influence of the noise spectra on the potentialities for communication to and from the helicopter and therefore the operational problems which may be encountered with use of the helicopter. It is suspected that the noise spectrum may be a controlling factor in the choice of the propulsion package inasmuch as it must be possible to operate within reasonable distances of the helicopter. These preliminary estimates will also form a basis for the preliminary design of the cabin walls of the helicopter and also the specification of the sound treatment within the cabin.

3.4.2 Background Data

During recent tests by this contractor, considerable new data have been collected regarding the noise spectra as well as other performance parameters for various sizes of pulsejet engines. Heretofore it has been assumed that the over-all chemical to acoustic efficiency of pulsejet engines of various sizes would be constant, in other words, that noise energy output would be proportional to the rate of fuel flow. Also, assuming that thrust per unit area would be constant, it followed that noise energy would be proportional to the square of the engine diameter. Lacking other data, these are the most logical and frequent assumptions.

Recent studies lead to a different basis for extrapolation, as will be evident.

The present report presents noise spectra for several sizes of engine at one distance and as a function of fuel flow rate. Since all the data on various sizes of pulsejet were taken at an azimuth angle of 90°, this position is chosen for the present correlation. This is reasonable also on the basis that the 90° position presents a noise spectrum which is very nearly the average spectrum for all angles around the engine. Furthermore, the helicopter cabin is located at 90° to the pulsejet centerline in the normal installation.

For the purpose of facilitating graphical analysis of noise data, it is convenient to reduce the noise spectrum of each engine to two significant parameters: (a) The over-all sound pressure level is a familiar quantity and in general is an indication of the low frequency output of the engine, since the spectra of pulsejet engines is generally steeply sloping. (b) As an indication of the high frequency output and for purposes of correlating noise spectrum with annoyance, communication interference, and deafening effects, a quantity is used which is coming into increasing use under the term "SPEECH INTERFERENCE LEVEL". This parameter is the average of the sound pressure level in the three octave bands 600-1200, 1200-2400, 2400-4800 cps and is commonly abbreviated as SIL.

3.4.3 Correlation of Pulsejet Noise Data

The data presented in Section 3.2 and 3.3 of the present report have been correlated on the bases of over-all noise level, "Speech Interference Level", and effects of multiple operation as follows:

3.4.3.1 Over-all Noise Level

The over-all noise level for each engine is plotted in Figure 12-a as a function of engine thrust. While each individual engine exhibits a general trend toward higher noise level at higher thrust (except for the 12.5 engine), there is no apparent trend between thrust and noise level considering the engines as a group. It is particularly interesting to note that the 6.75 inch "long-tailpipe" engine produces appreciably more thrust than the "standard" 6.75 inch engine, yet is considerably quieter. The long tailpipe engine also offers better specific fuel consumption. Based on Figure 12-a, it is concluded that pulsejet over-all noise level is not primarily controlled by engine size, and that a level of 145 db at 3 feet abeam is a reasonable estimate for pulsejets having maximum thrusts of 500 pounds or less.

The conclusion that noise level is essentially independent of engine size is so contradictory to experience with other types of jet engines that it must be viewed with suspicion and used with caution. Nevertheless, no other conclusion can be logically supported by the present data, which covers engines with a tenfold variation in maximum thrust. The value of 145 db recommended above is sufficiently greater than the lowest value shown for peak thrust operation (139 db for a 6.75" engine) that it is surely achievable with pulsejets producing up to 500 pounds maximum thrust, even if later data should demonstrate a rising noise level with increasing size.

A possible explanation of the unusual results of the present correlation lies in the noise attenuation with distance for pulsejets of various sizes as discussed later in Section 3.4.3.4; however, it is not believed that this effect is entirely responsible for the apparent independence of pulsejet noise and size.

3.4.3.2 "Speech Interference Level"

The SIL data for each engine is plotted in Figure 12-b as a function of thrust (expressed as a percentage of maximum thrust for the particular engine). The correlation here is surprisingly good, with maximum thrust noise levels falling within ± 1 db of 130 db for all but the 5" engine (which is at 125 db). The slope of db vs % thrust appears to be reasonably approximated by the line shown, which infers that sound energy is proportional to the third power of the thrust level for a given engine. The assumption that noise energy at peak thrust is independent of engine size, which appeared reasonable in view of the over-all noise data, is strongly emphasized by the SIL data. In general, then, it may be seen that to minimize noise level for a given pulsejet thrust output in pounds, the pulsejet should be made as large as possible and should be operated at part throttle.

3.4.3.3 Effects of Multiple Operation

The most applicable data available for prediction of multiple pulsejet noise effects are in Reference 3 and in Section 3.3 of this report. In each case, a reduction of about 5 db in over-all noise level is shown for out-of-phase operation of dual engines. The high frequency portion of the spectrum is represented by the SIL, which appears to increase approximately 3 db (as would be expected for a case with double the sound energy). An acoustic shroud was tested in connection with the dual engine tests of Section 3.3 with mixed results. A reduction of 6-8 db in SIL was obtained, but was accompanied by an increase in over-all level to a value comparable to two engines operating in-phase. It is felt that this first attempt at noise shrouding happened to cause an unfortunate resonant condition and that a shroud can be designed which will give high frequency attenuation without interfering with the out-of-phase reduction of over-all noise level. However, the triple requirements of low frequency attenuation, high frequency attenuation, and unaffected thrust will make the development of a suitable shroud a very difficult problem.

3.4.3.4 Attenuation of Noise With Distance

Application of noise data to helicopter studies requires a reasonable basis for determining the decrease in sound energy as a function of distance from the source. Lacking other information, the usual assumption is the inverse square law. However, data from Reference 2 on the 6.75" and 9.4" engines gives a more reasonable basis for this computation for distances out to 50 feet. Figure 13 shows the behavior with distance on the 90° azimuth for both the 6.75" and 9.4" engines. A line showing inverse square decrease is also given for comparison. It is clear that at close range the decrease in the sound level is not so rapid as inverse square. This fact is the more surprising for such high sound levels where, for a simple source, the decrease is usually more rapid than inverse square. The observed effect is probably due to the fact that the pulsejet engine is neither a small nor a simple source. At low frequencies the resonant tube behavior presents a dipole source, whereas at high frequencies the noise is

generated in a generally divergent conical region of reacting and highly turbulent gases. It is highly possible that for small distances from the pulsejet, the attenuation would be better correlated against distance expressed in terms of a characteristic engine dimension rather than in feet. This possibility is supported by the over-all noise level data of Figure 13, which shows a smaller attenuation rate for the larger engine; but it is denied by the SIL data, which shows identical attenuation for the two engines. Furthermore, the higher frequencies composing the SIL are largely generated in the distributed turbulence of the exhaust jet and therefore should be more affected by scale effects than the discrete resonant frequencies which determine the over-all noise level and which would be expected to emanate directly from the engine exhaust nozzle. Unfortunately, this question was raised too late in the program to permit the necessary data to be taken so no final conclusion is possible at present. If attenuation with distance is a strong function of engine size, the 3 foot location chosen for the preceding noise vs. size correlation may be responsible for the remarkable indication reached during that study. It is not seriously believed that the attenuation rates beyond 3 feet are so strongly affected by engine size as to render invalid all correlations based on 3 foot data --- nevertheless, this possibility must be considered in any future application of the data from the present report.

In the absence of more complete data, the solid curves of Figure 13 are recommended for use in extrapolating pulsejet noise data to 50 feet. Beyond 50 feet, the slope of the data is such as to indicate the valid application of conventional "square-law" and atmospheric damping attenuation factors.

3.4.3.5 Predicted Pulsejet Noise Levels

The following table presents the expected noise performance of pulsejet engines based on presently available data:

Configuration	Over-all Noise Level db	Speech Interference Level db
Single engine (to 500 lb. thrust)	145	130
Unshrouded dual engine (to 1000 lb.thrust)	140	133
Shrouded dual engine (to 1000 lb. thrust)	140	127

Notes:

1. Each subsequent doubling of engine number will result in addition of 3 db to over-all and SIL values.
2. These data for position 3 feet from engine centerline on a perpendicular midway along the engine length.
3. For noise attenuation with distance, see Figure 13.
4. For variation of noise with azimuth position, see Reference 2.

4.0 CONCLUSIONS

A. Noise spectra have been measured for engines ranging in size from 5" diameter to 12.5" diameter. It is found that size is not the controlling factor in noise output.

B. Each engine has been studied for the influence of rate of fuel flow on noise output. It is found that for very low rates of fuel flow, the high frequency portion of the spectrum is comparatively reduced.

C. Operating frequency has also been studied as a function of rate of fuel flow. It is found that in general the fundamental frequency decreases as the fuel flow is increased.

D. The influence of tube geometry is indicated by the fact that, for a given rate of fuel flow and chamber diameter, the high frequency noise is decreased and the thrust is increased if a longer tailpipe with larger diameter is used.

E. There is an indication that a primary factor in determining high frequency noise spectrum is the exit velocity of the gases.

F. Continuing the development of twin engines in parallel configuration, it is found that an acoustically treated cowl surrounding the tailpipes produces a useful amount of high frequency noise reduction. Unfortunately, the advantage of low frequency noise cancellation is largely lost in the present configuration. The effect on thrust is not indicated because the cowl was hand-held.

G. The noise reduction for the twin engine opposed configuration with an acoustically-lined tailpipe duct could not be evaluated because the lining material was blown out immediately upon starting.

H. A built-in acoustical filter reduced the high frequency noise with severe loss of thrust.

I. Two types of serrated edges at the tailpipe exhaust proved ineffective.

5.0 REFERENCES

1. P.S. Veneklasen, "Noise Control", AH Report RR-23, dated 16 March 1954.

2. P.S. Veneklasen and L.E. Emmerich, "Measurements and Analysis of the Physical Characteristics of Pulsejet Engine Noise", AH Report 163-K-1, dated 28 September 1951.

3. C.H. Dessin, "Development of the MX-1660 Helicopter Rotor - Progress Report for June 1952", AH Report 175-D, dated 14 July 1952.

4. R.W. McJones, "MX-1660 Powerplant Development - Predicted Characteristics of Final Powerplants", AH Report 1757B-402, dated 30 November 1954.

5. P.S. Veneklasen, "Noise Analysis", AH Report RR-24, dated 22 March 1954.

Figure 1

6.75" "STANDARD" SINGLE SHELL ENGINE

	Thrust lb.	Fuel Flow pphr	Freq. cps
1.	23.0	100	141
2.	32.0	120	141
3.	36.4	140	141
4.	37.5	160	140
5.	37.0	180	140
6.	36.7	200	140

Microphone Position
3' - 90°

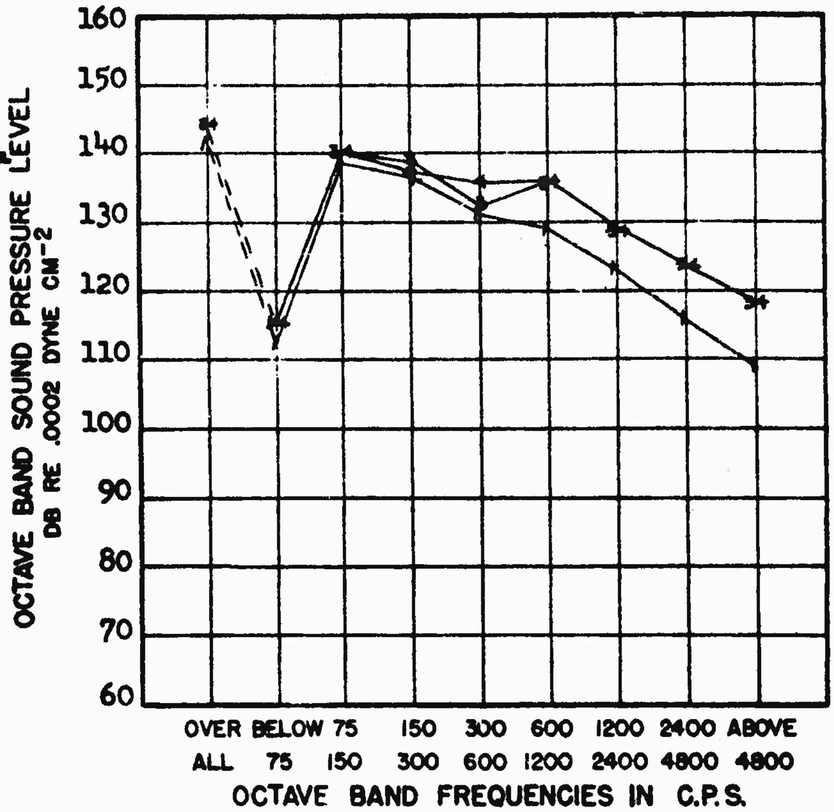


Figure 2

6.75" SINGLE SHELL ENGINE WITH LONG TAILPIPE

	Thrust lb.	Fuel Flow pphr	Freq. cps
1.	28.0	110	118
2.	45.9	150	112
3.	53.0	190	112

Microphohe Position
3' - 90°

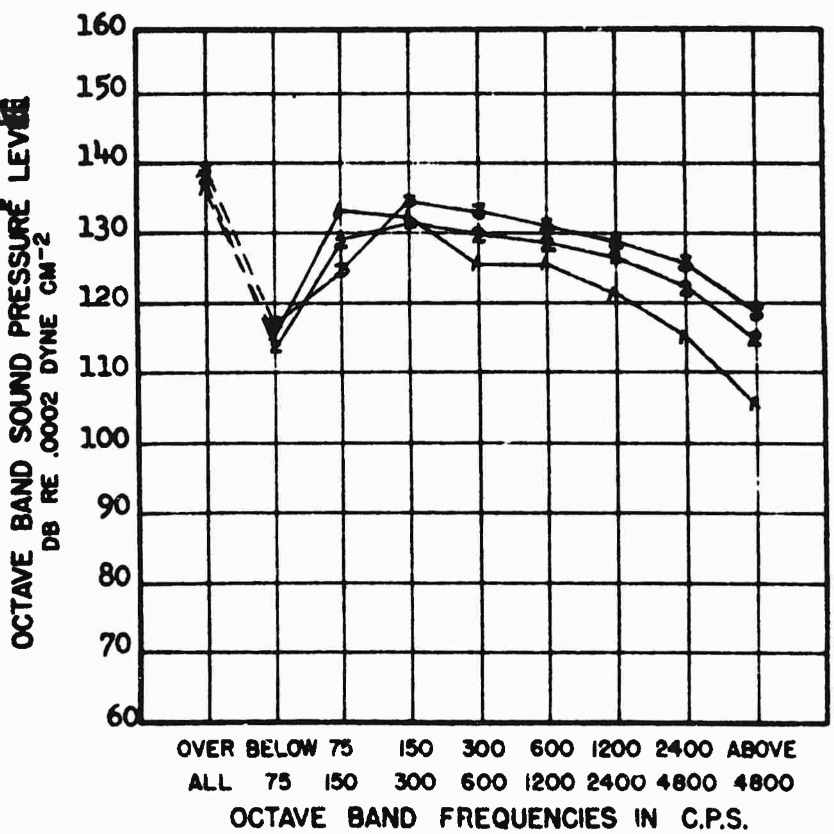


Figure 3

7.5" SINGLE SHELL ENGINE

	Thrust lb.	Fuel Flow pphr	Freq. cps
1.	8.5	90	141
2.	45.5	150	125
3.	52.0	190	128

Microphone Position
3' - 90°

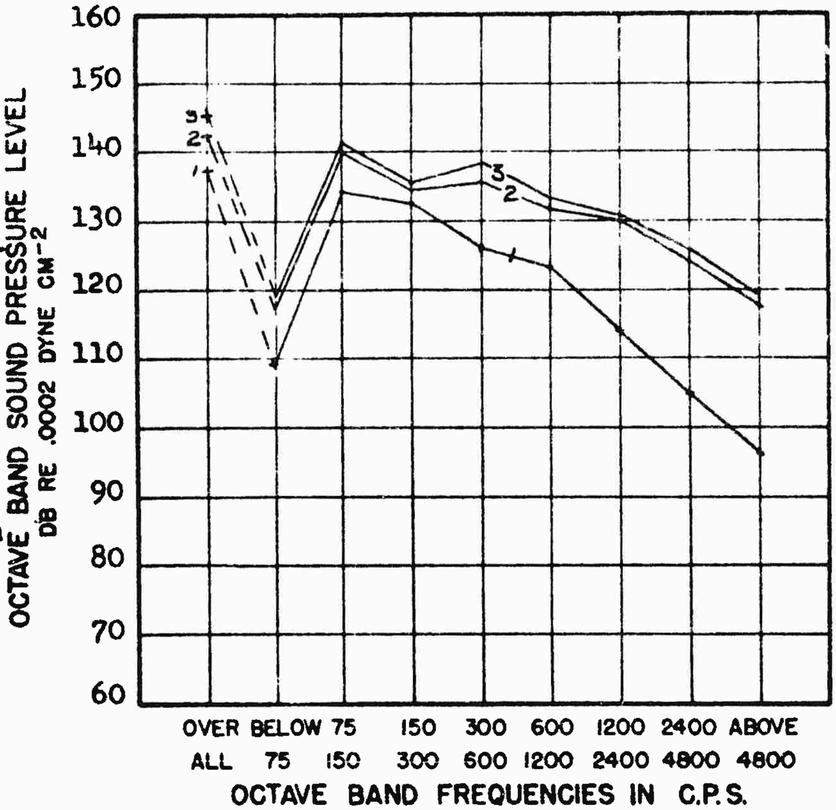


Figure 4

7.5" CONICAL ENGINE

	Thrust lb.	Fuel Flow pphr	Freq. cps
1.	8.3	90	150
2.	37.3	150	131
3.	44.5	220	132

Microphone Position
3' - 90°

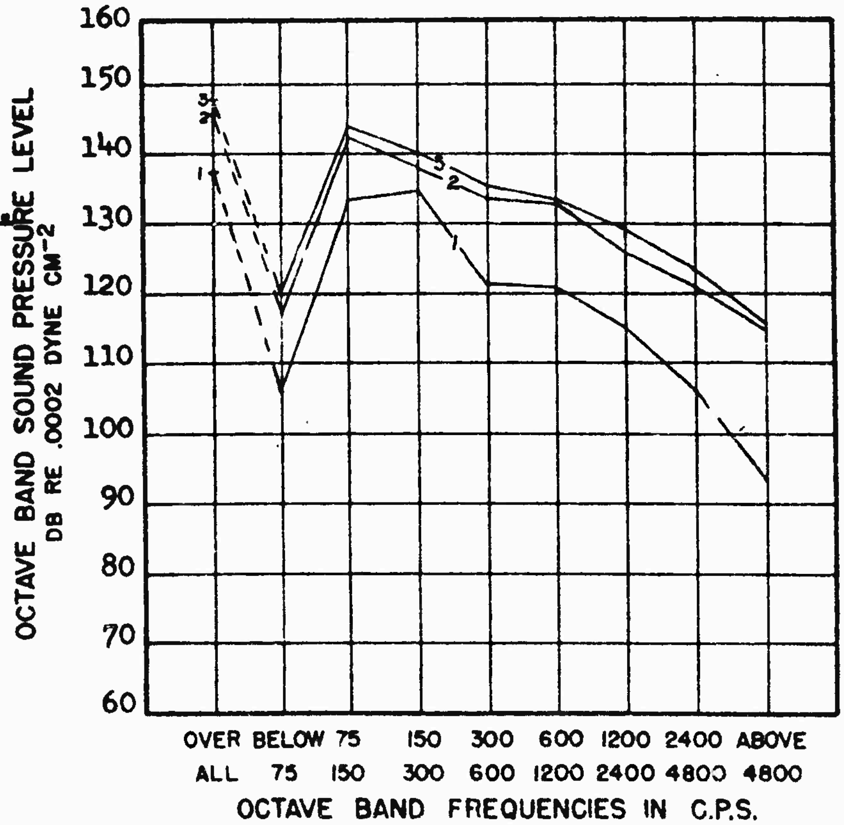


Figure 5

12.5" SINGLE SHELL ENGINE

	Thrust lb.	Fuel Flow pphr	Freq. cps
1.	38	270	94
2.	72	350	94
3.	190	550	80
4.	190	650	73

Microphone Position
6' - 90°

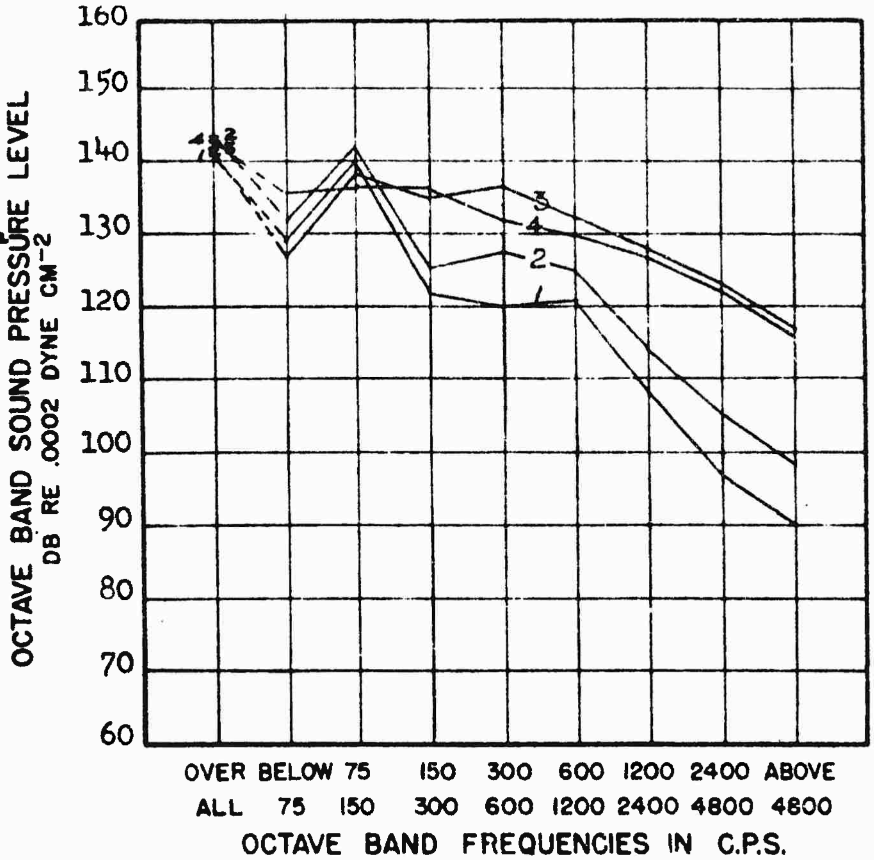
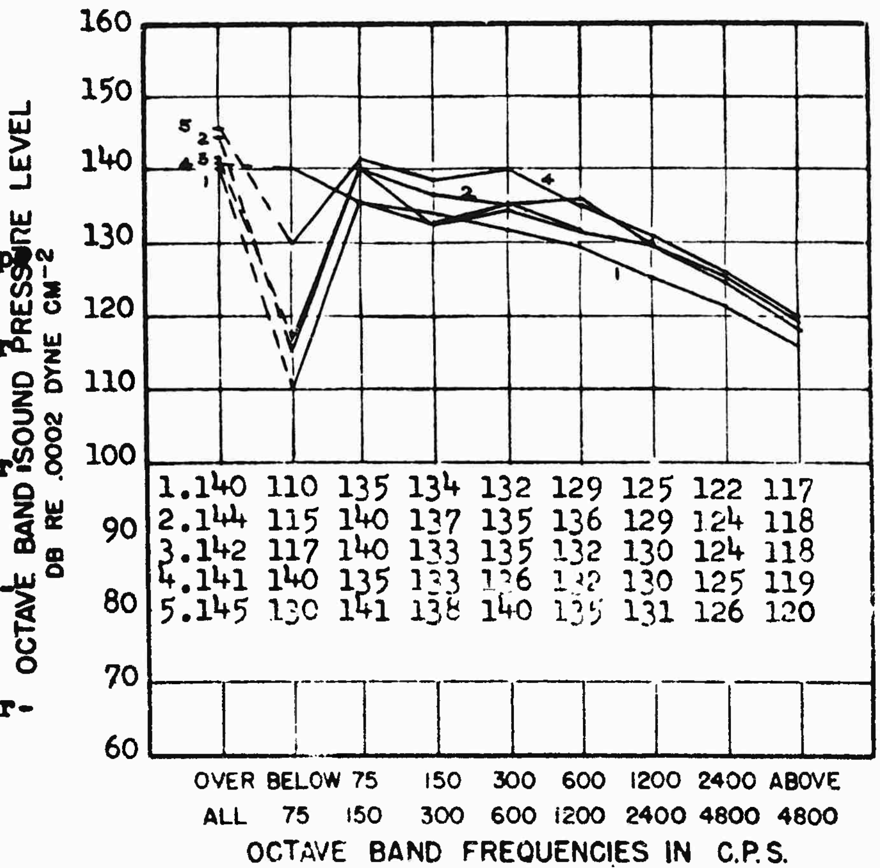


Figure 6

COMPARISON OF NOISE SPECTRA VS. ENGINE SIZE

1. 5" Engine: 21.4 lb.at 75 pphr-140cps
2. 6.75"Standard: 36.4 lb.at 140 pphr-141 cps
3. 7.5" Engine: 45.5 lb.at 150 pphr-125 cps
4. 9.4" Engine: 98 lb.at 240 pphr-93 cps
5. 12.5" Engine: 190 lb.at 550 pphr-80 cps

Microphone Position
3' - 90°



1.	140	110	135	134	132	129	125	122	117
2.	144	115	140	137	135	136	129	124	118
3.	142	117	140	133	135	132	130	124	118
4.	141	140	135	133	136	132	130	125	119
5.	145	130	141	138	140	135	131	126	120

Figure 7

COMPARISON OF 6.75" ENGINES

1. 6.75" Standard: 36.4 lb. at 140 pphr
2. 6.75" With Long Tail Pipe: 45.8 lb. at 150 pphr
3. 6.75" with Acoustic Filter: 22.8 lb. at 150 pphr

Microphone Position 3' - 90°

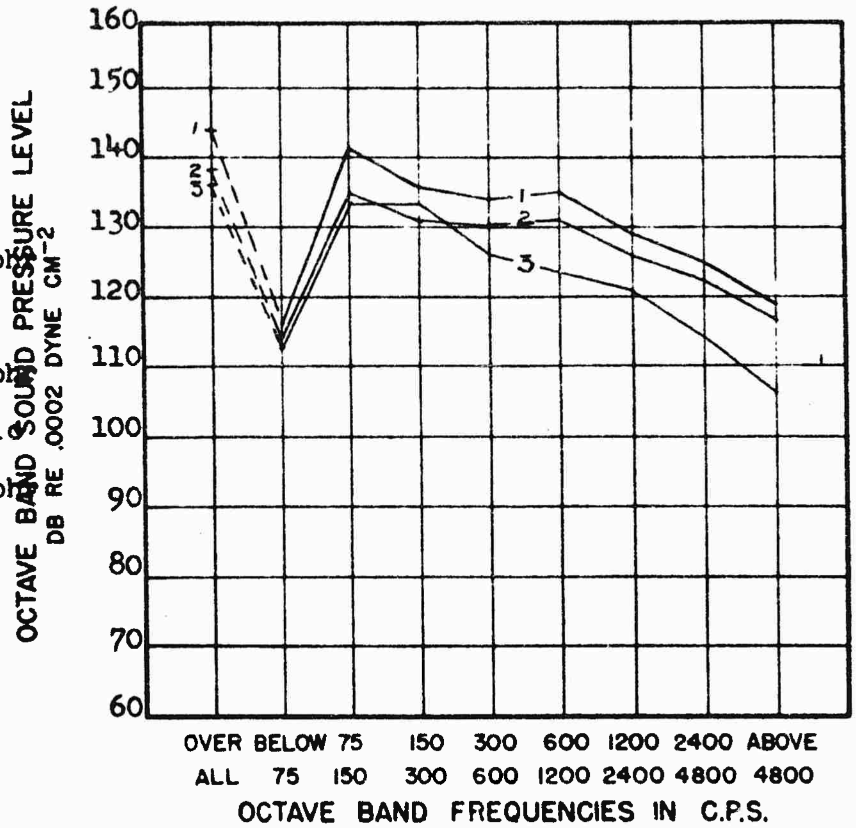


Figure 8

TWIN 6.75" ENGINES - PARALLEL CONFIGURATION

1. Without Noise Shroud: 69.7 lb. at 151 pphr each
2. With treated Shroud: 70.1 lb. at 155 pphr each

(Shroud was hand-held.)

Microphone Position 3' - 90°

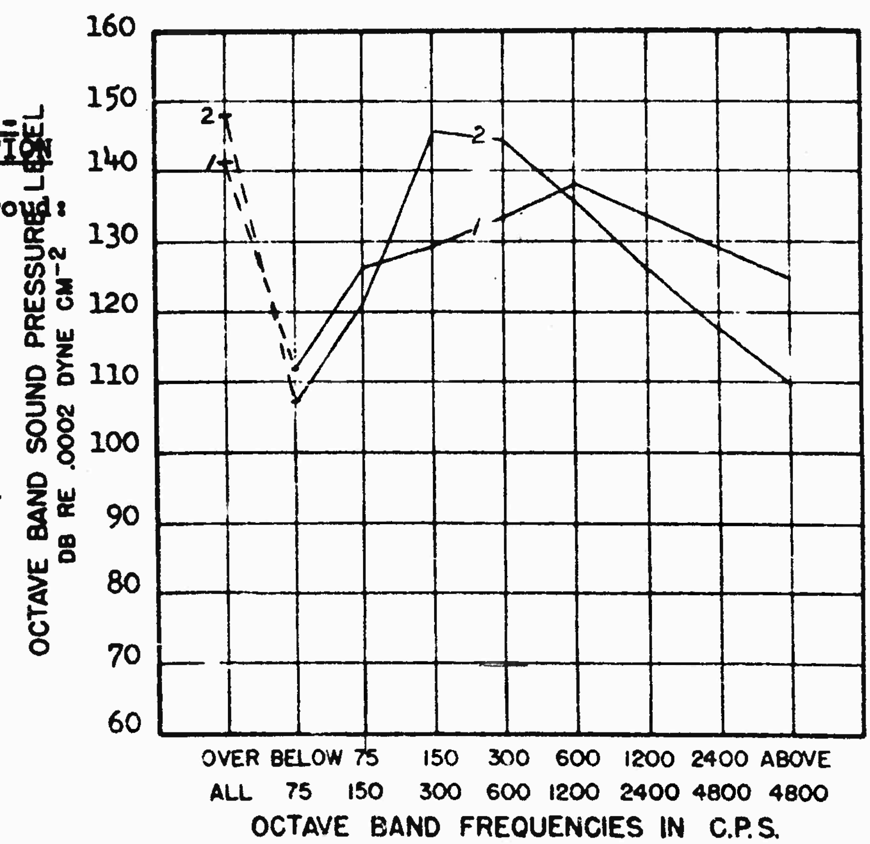


Figure 9

TWIN 6.75" ENGINES - OPPOSED CONFIGURATION WITH UNTREATED DUCT.

Fuel Flow:
80-190 pphr. each
Thrust:
9.5 - 14 lb.
Frequency:
169-185 cps (each engine)
(Order of runs uncertain.)

Microphone Position
3' - 90°

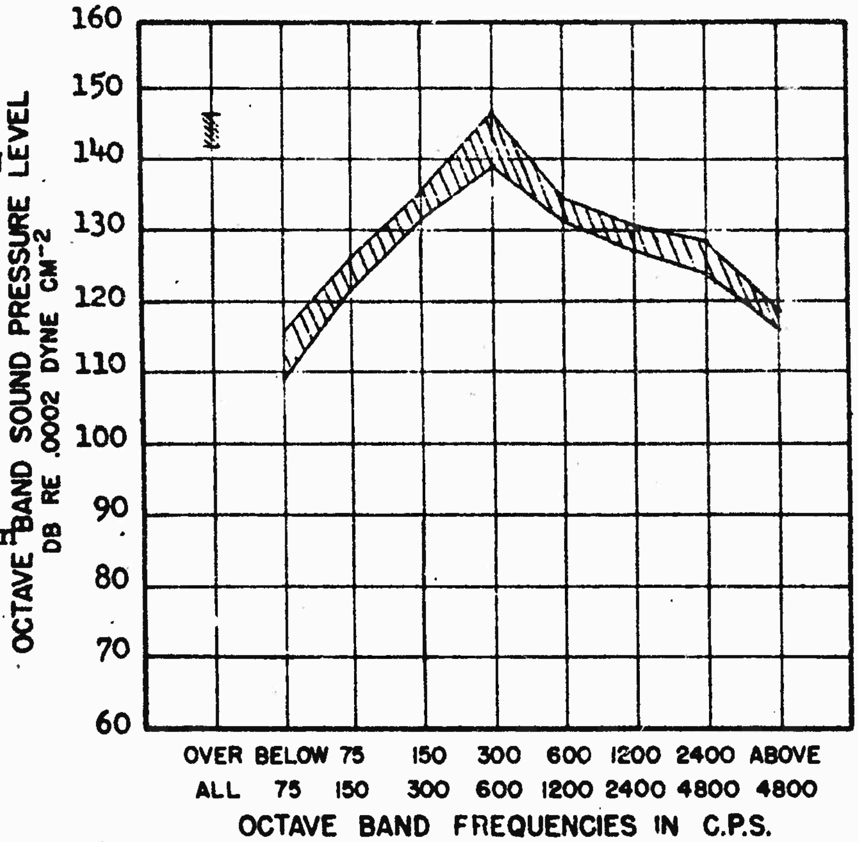


Figure 10

6.75" SINGLE SHELL WITH LONG TAILPIPE AND TABS.

	Thrust lb.	Fuel Flow pphr	Freq. cps
1.	26.8	110	115
2.	43.5	150	112
3.	51.3	190	112
4.	45.9	150	112 (without tabs)

Microphone Position
3' - 90°

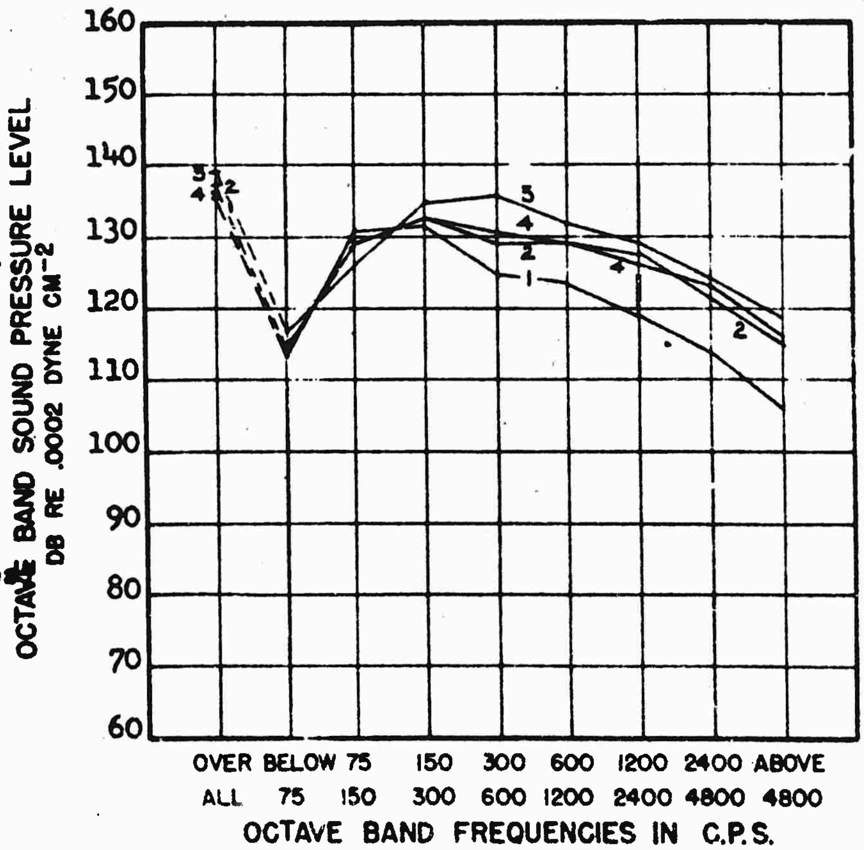
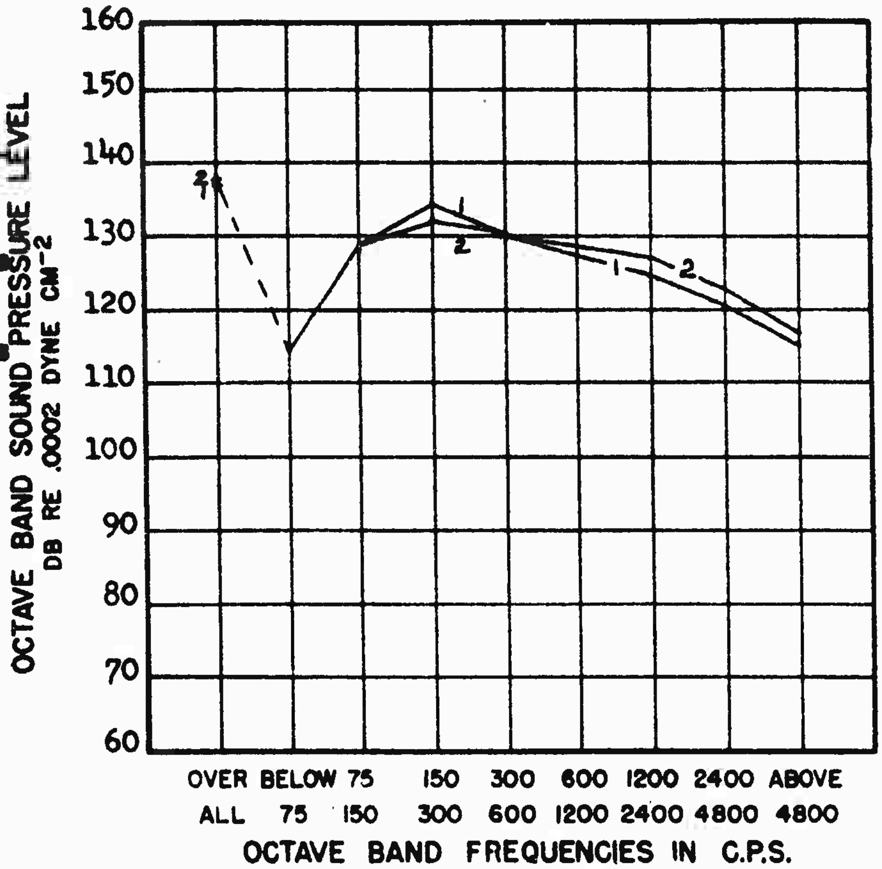


Figure 11

6.75" SINGLE SHELL WITH LONG TAILPIPE AND SLOTTED FLARE

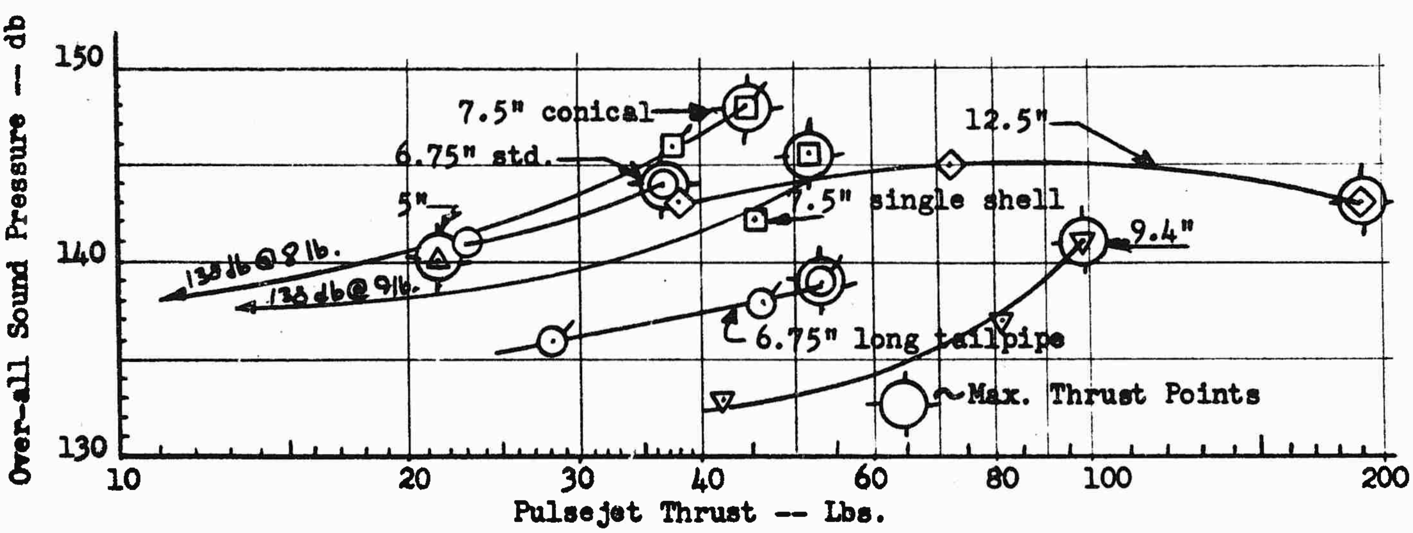
1. 40 lb. Thrust at 150 pphr. - 111 cps
2. 45.9 lb. Thrust at 150 pphr. - 112 cps (without slots)

Microphone Position 3' - 90°



EFFECT OF THRUST LEVEL ON PULSEJET NOISE

a) Over-all Noise Level Correlation



b) Speech Interference Level Correlation

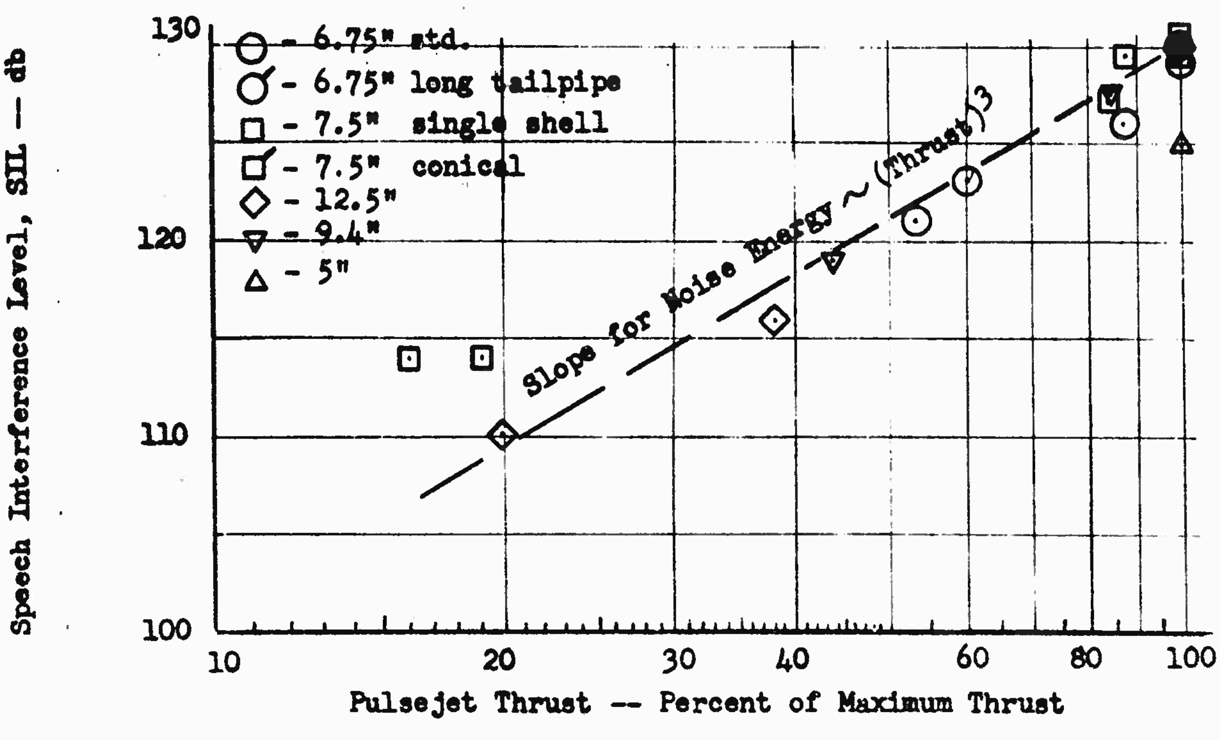
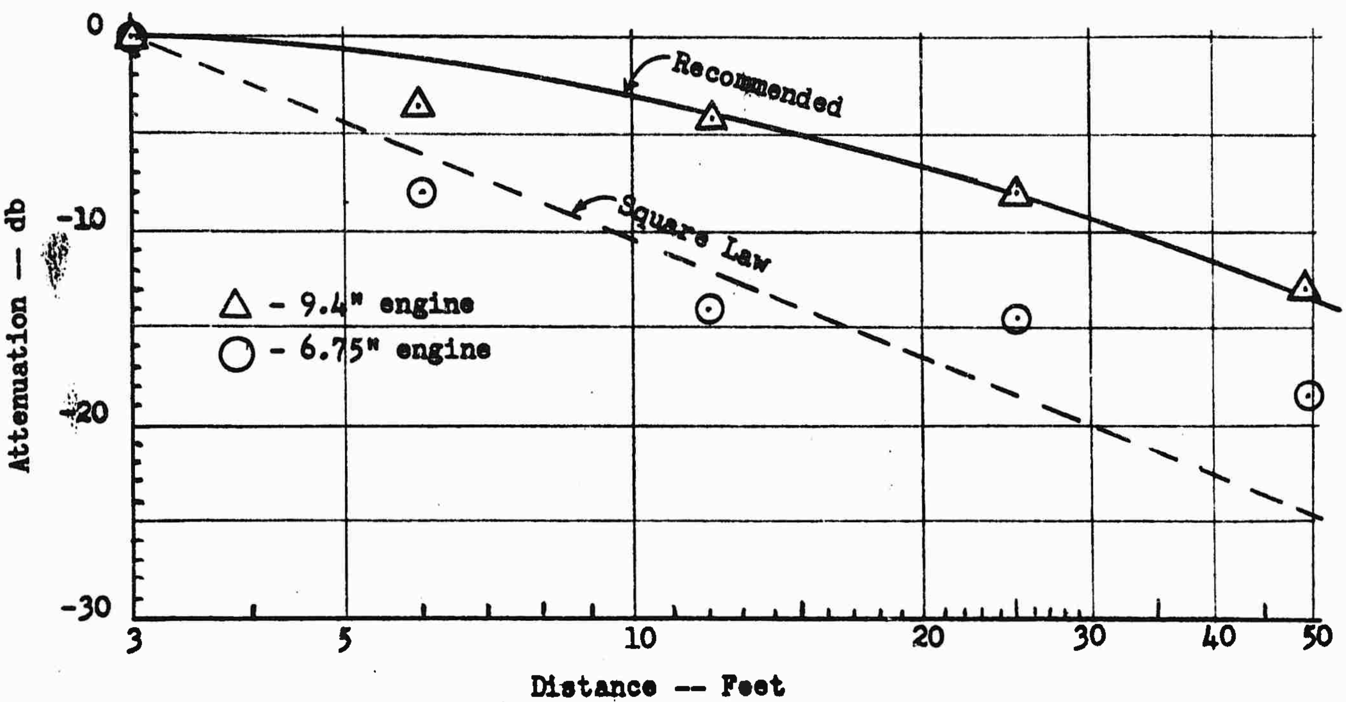


Figure 12

PULSEJET NOISE ATTENUATION WITH DISTANCE

a) Over-all Noise Level



b) Speech Interference Level, SIL

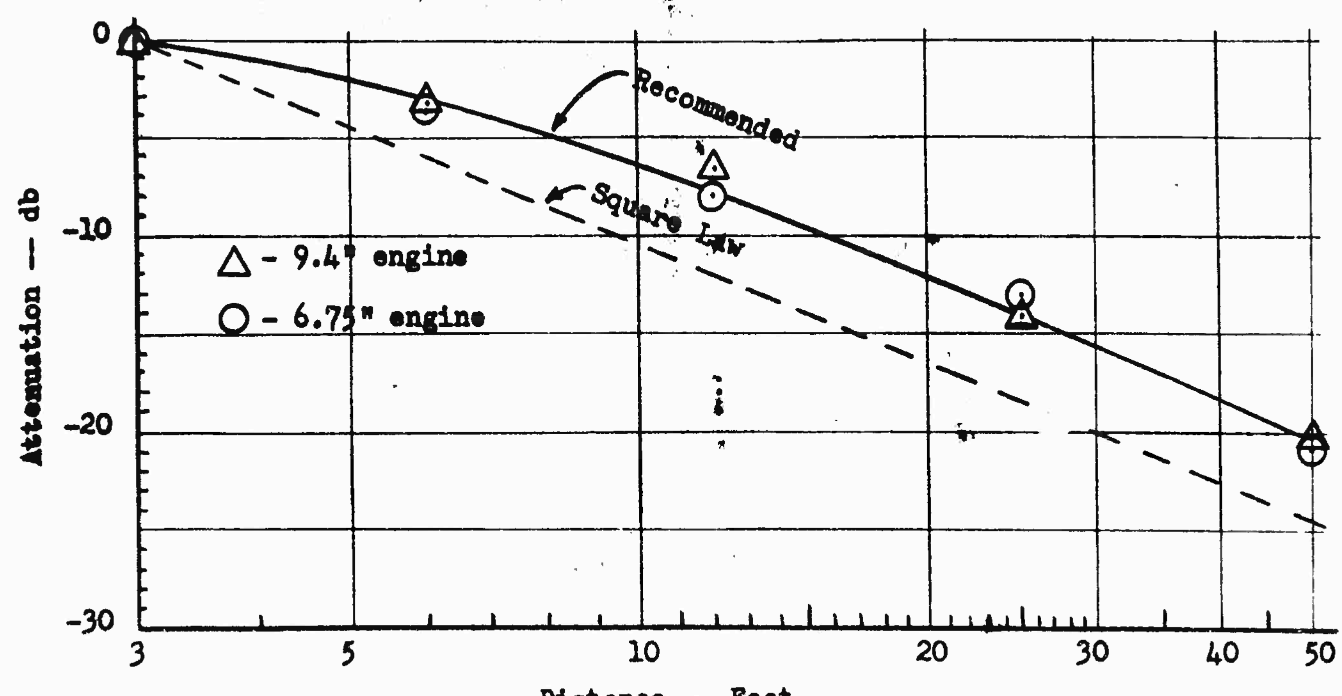


Figure 13

Photo 1

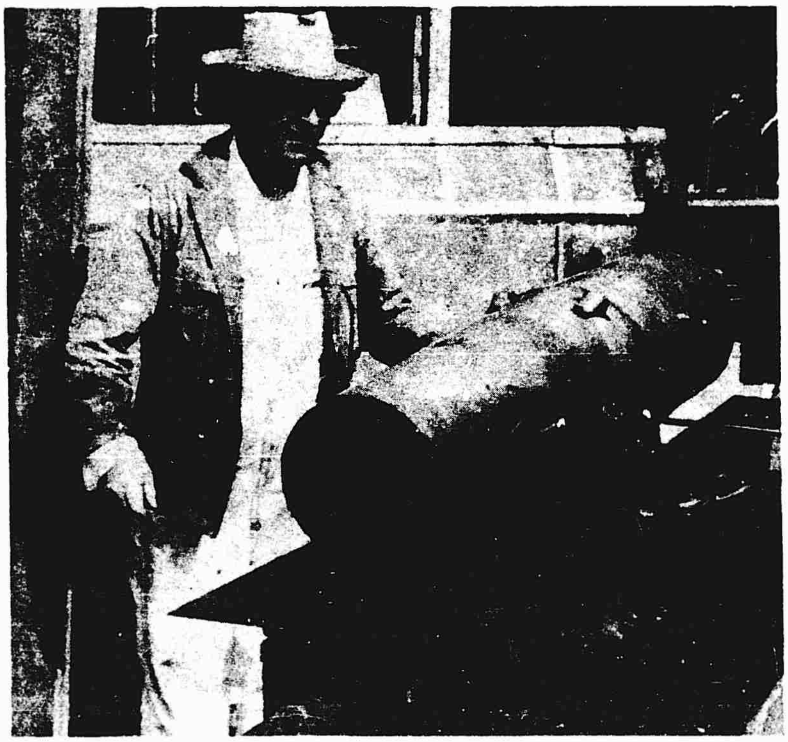


Photo 2

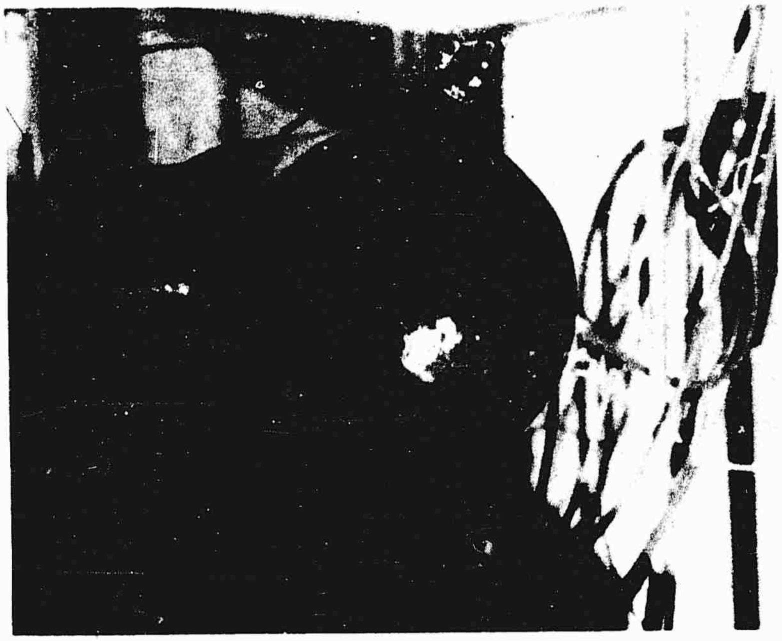


Photo 3

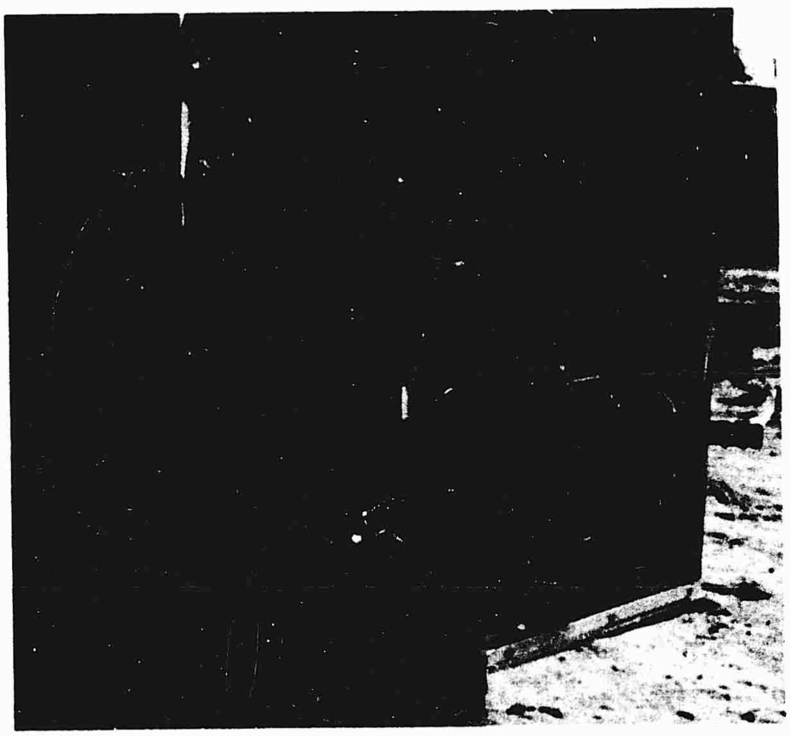


Photo 4

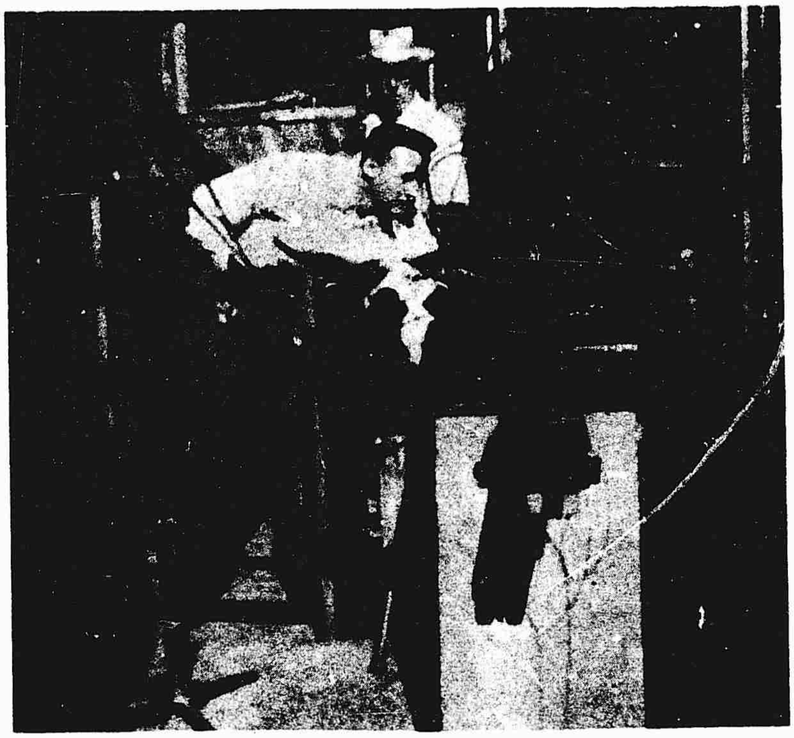


Photo 5

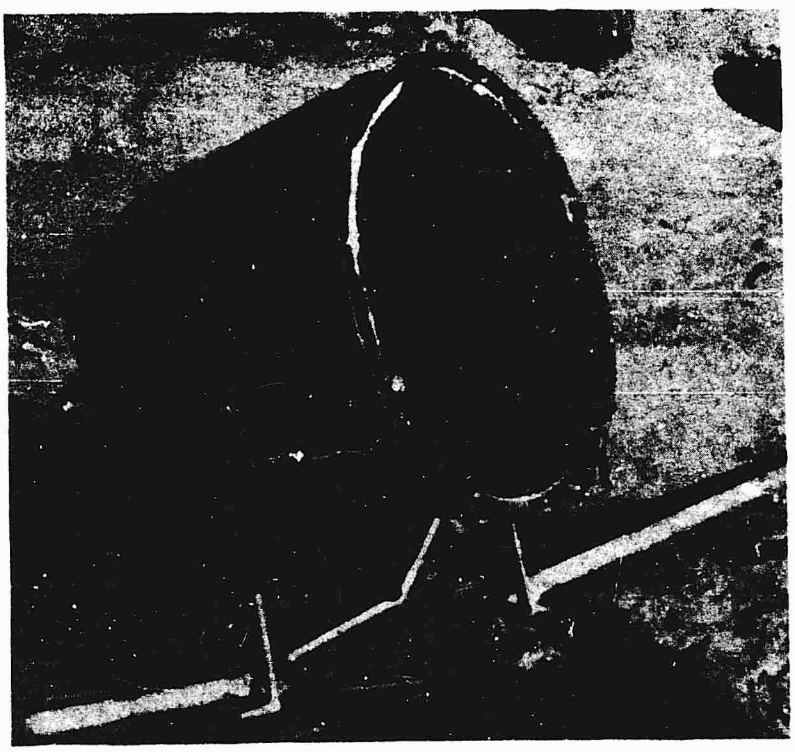


Photo 6

Photo 7

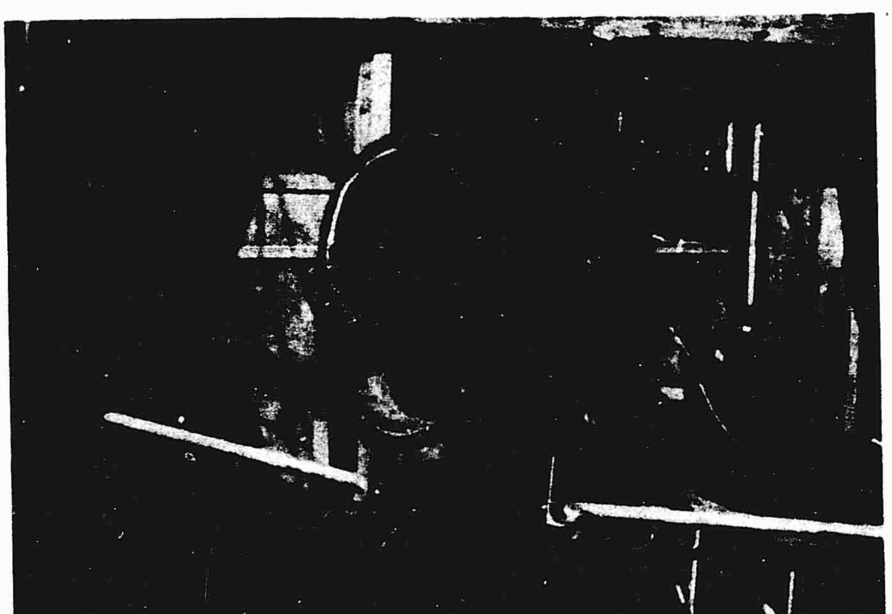


Photo 8

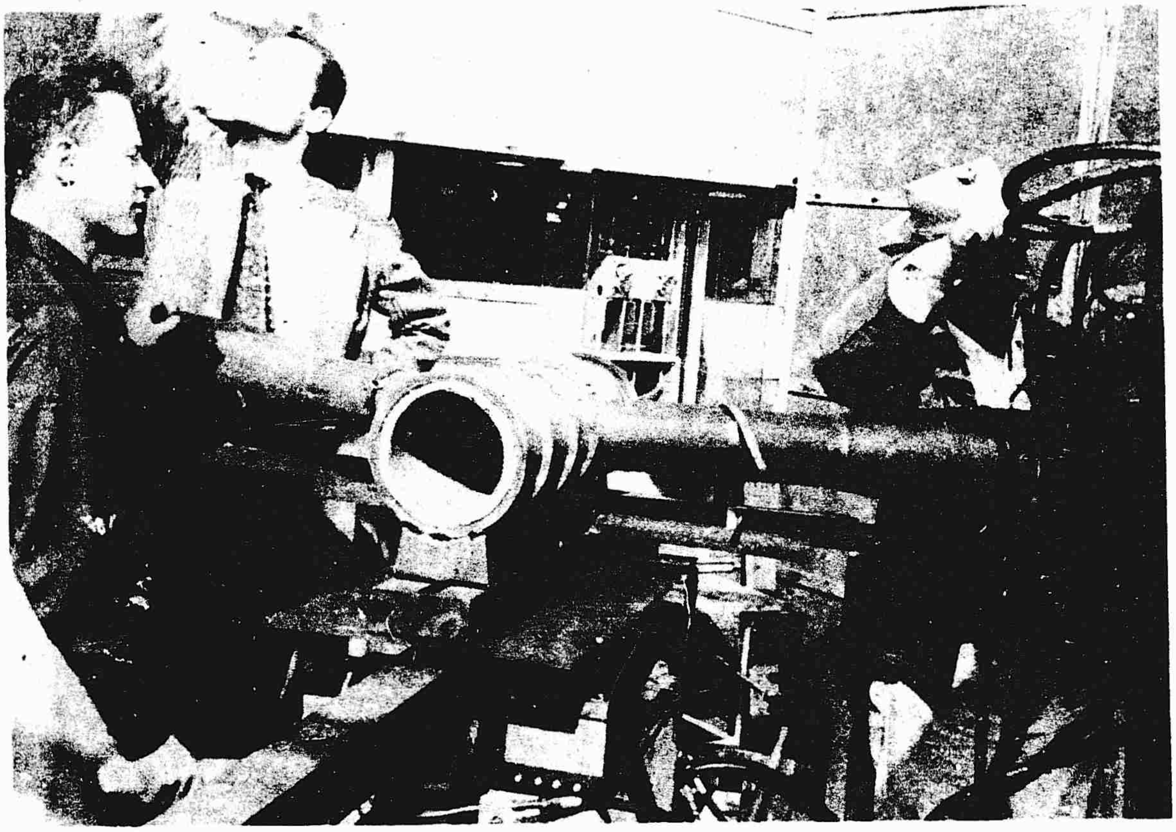


Photo 9

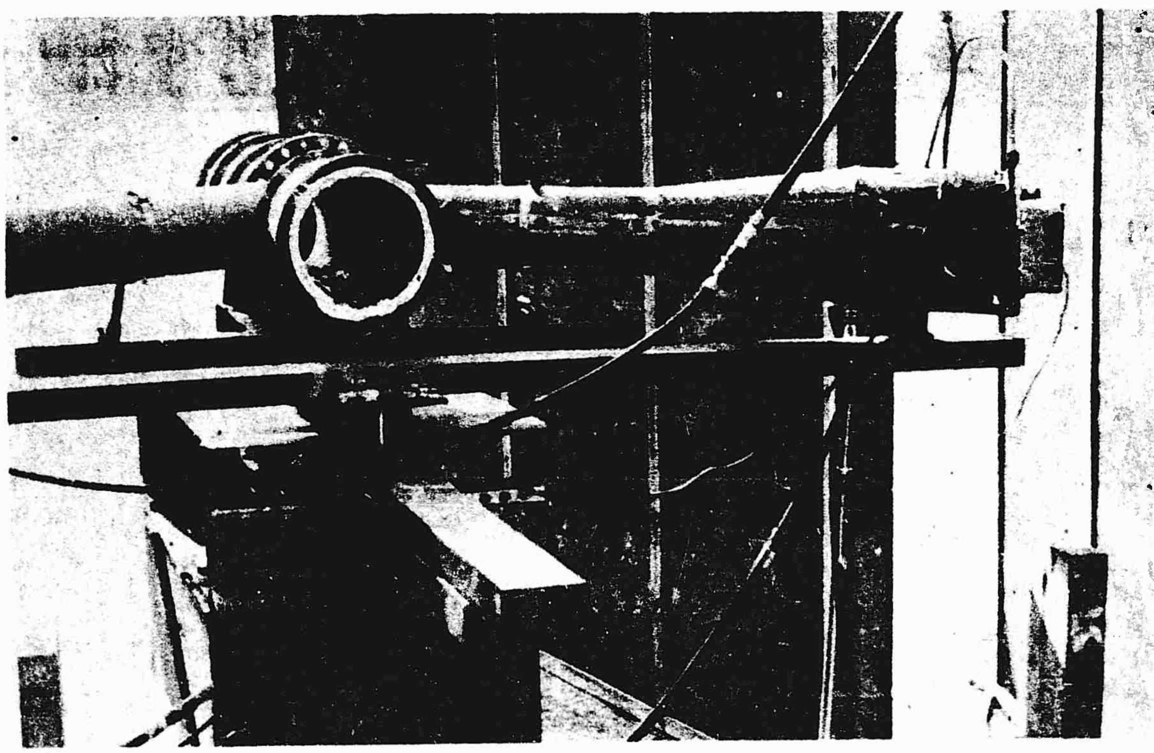


Photo 10

Photo 11

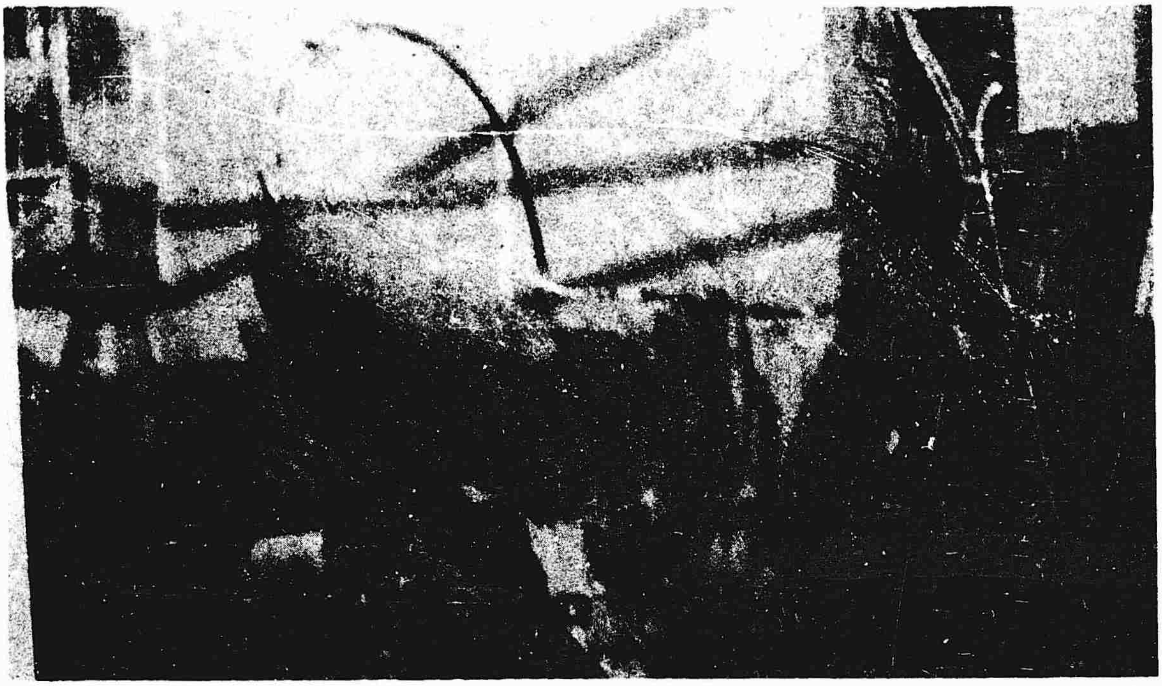


Photo 12

Photo 13